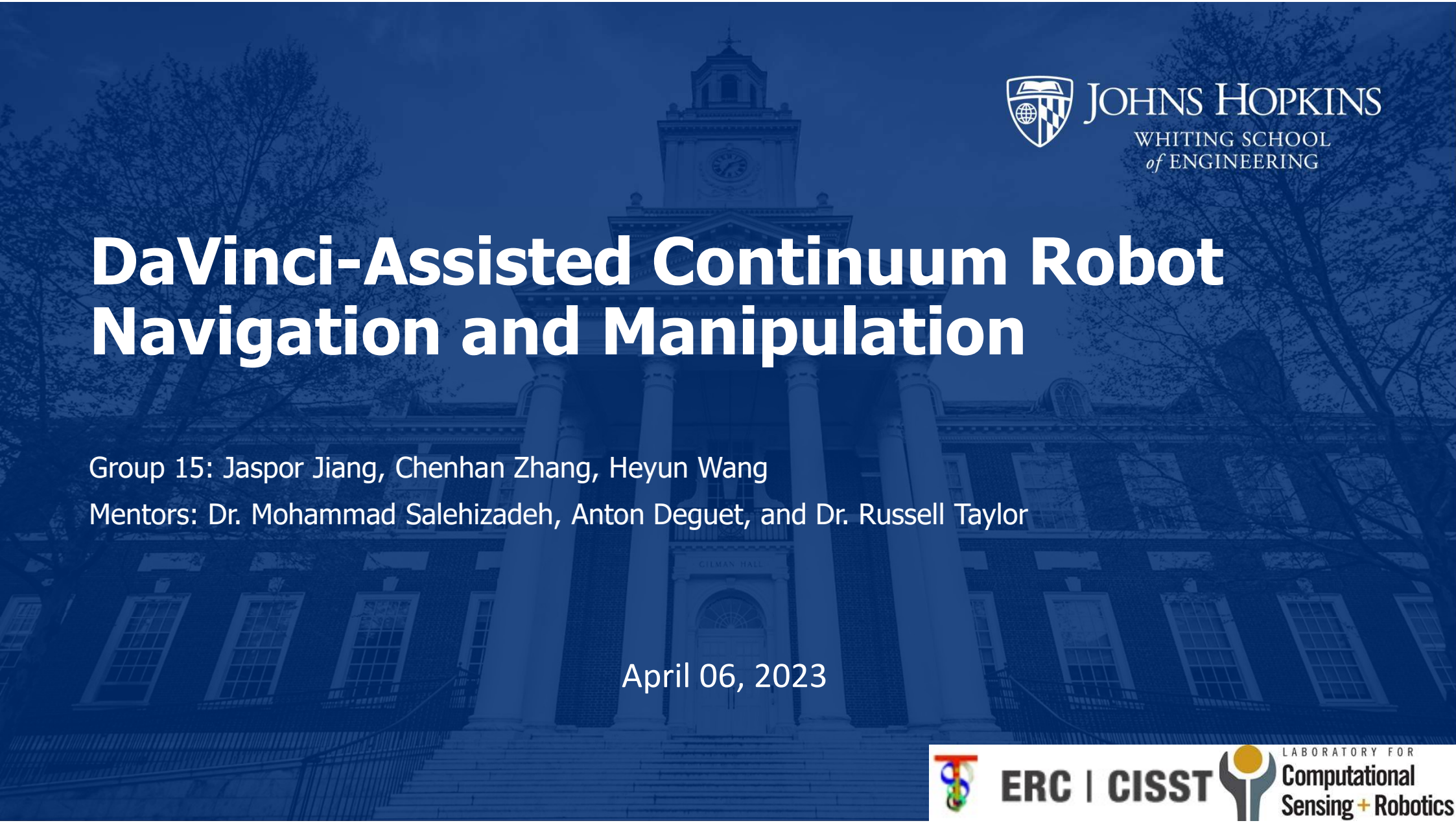

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DaVinci-Assisted Continuum Robot Navigation and Manipulation

Group 15: Jaspor Jiang, Chenhan Zhang, Heyun Wang

Mentors: Dr. Mohammad Salehizadeh, Anton Deguet, and Dr. Russell Taylor

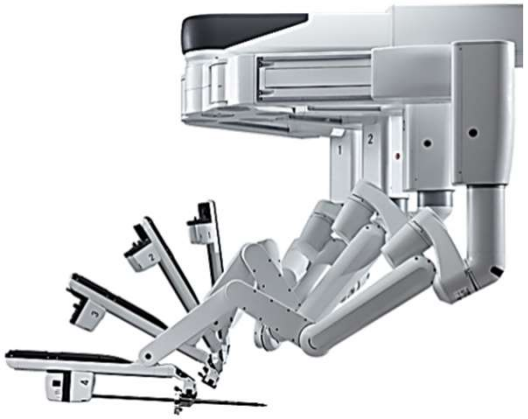
April 06, 2023

ERC | CISST
LABORATORY FOR Computational Sensing + Robotics

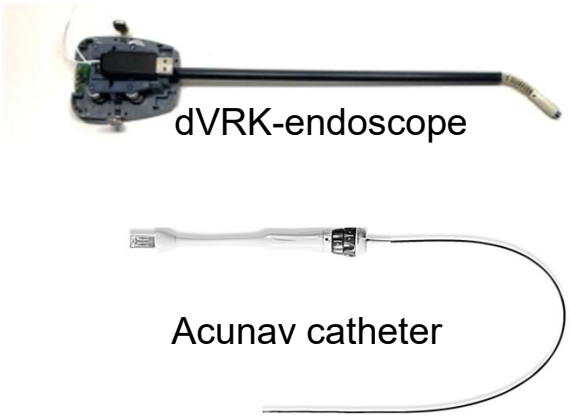
Project Summary

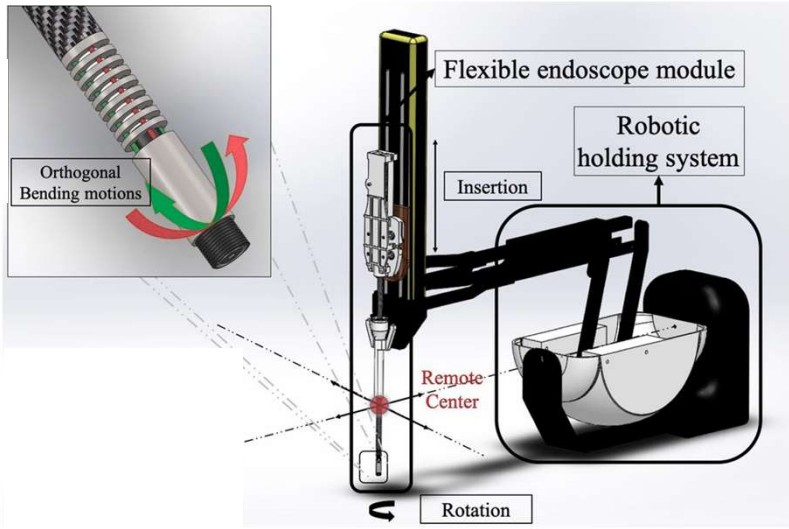
Goal: build a continuum robot navigation and manipulation system with tendon-driven continuum robot end to improve the reachability of the DaVinci robot arm.

- Redesign DaVinci Research Kit with flexible robot end
- Construct forward kinematics model of dVRK-endoscope and dVRK-Acunav
- Apply ROS navigation and manipulation on redesigned dVRK



DaVinci Robot: robohub.org/intuitive-surgical-da-vinci-surgical-system-gets-big-endorsement/





Patient Side Manipulator (PSM) kinematics with flexible endoscope[1]

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Dependencies Update

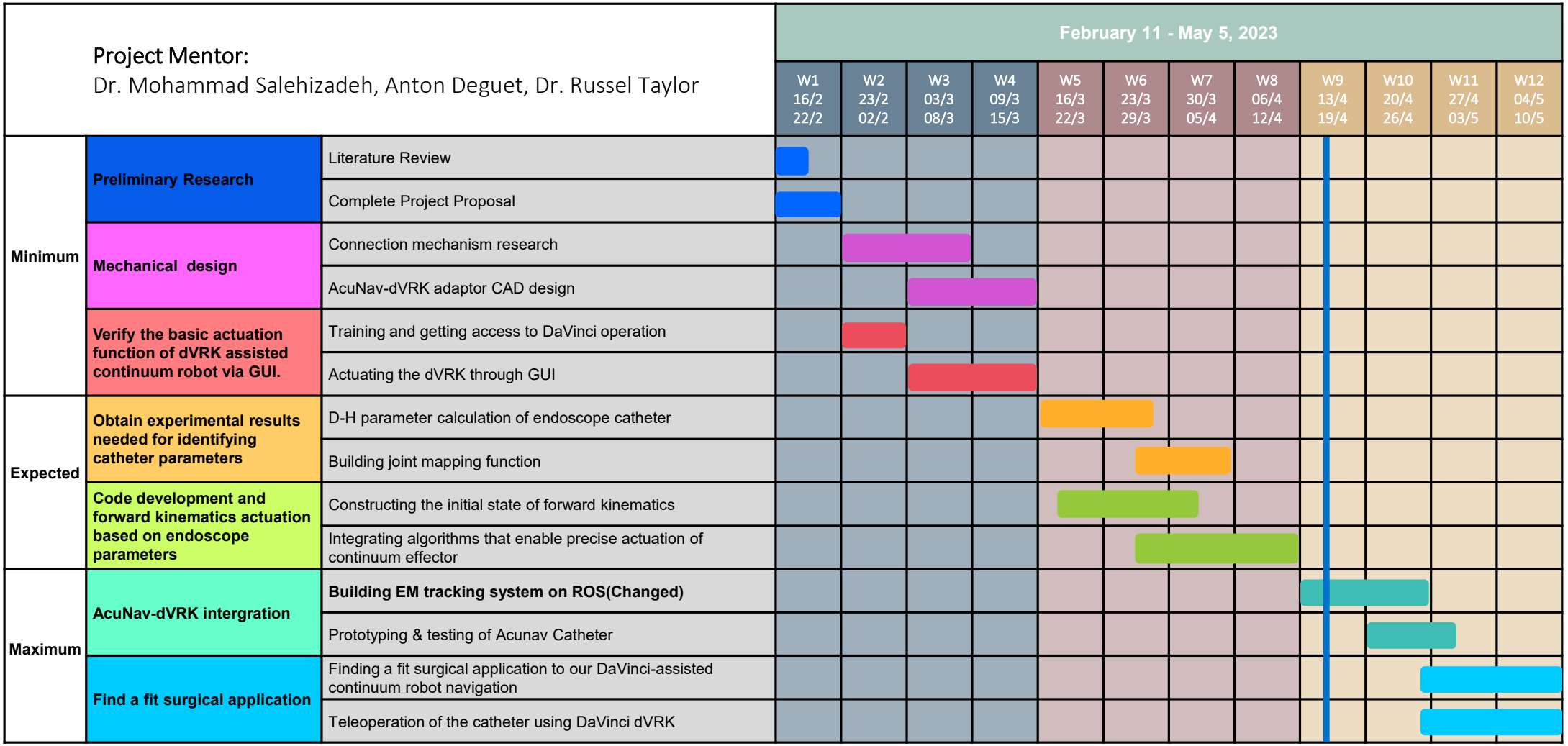
Dependency	Need	Contingency plan	Planned	Hard	Status
End-effectors for testing	DaVinci dVRK, endoscope and Acunav catheter	Rigid dVRK in Robotorium	Feb.27	Feb.29	
Access to hardware Models	Aquire CAD Model of Acunav catheter and DaVinci baseplate	**Manually measurement and modeling**	Feb.27	Feb.29	
Software installation: ROS, Python, CISST library	License, crtk and dvrk packages	Use Lab Computer with pre-installed software	Feb.24	Feb.27	
Access to dVRK	Access and training from Anton Deguet	N/A	Feb.25	Mar.02	
Identification experiments of continuum end effector	EM tracking system ~~Optical marker~~ ~~Test weights~~ (removed)	from LCSR repository	Apr.07	Apr.17	
Ultrasound imaging of Acunav	Phantom for testing	3D print a model for testing	Apr.22	Apr.27	

Project Milestones Update

	Key Milestones	Results/Deliverables	Deadline	Status
minimum	Literature & background review	Papers of project proposal and background report	Feb 22	Done
	Connection mechanism research	Document of disassembled dVRK components	Mar 08	Done
	Acunav-dVRK adaptor mechanical design	CAD model of dVRK-Acunav	Mar 15	Done
	Actuating the dVRK through GUI	A detailed documentation of dVRK user guideline	Mar 17	Done
expected	D-H parameter calculation of endoscope catheter	Documented json scipt of dvrk-endoscope	Mar 25	Done
	Building joint mapping function	Documented python file that use DH parameters and joint mapping function to actuate continuum dvrk-endoscope	Apr 04	Done
	Integrate algorithms that enable precise actuation of continuum effector	A video demo of dvrk-endoscope motion that can follow specific path	Apr 12	Done
	Clarifying project requirements and specification (added)	Detailed documentations of requirements, functional specifications, and system design	Apr 06	Done
maximum	**Building EM tracking system on ROS (modified)**	An integrated dvrk with EM sensor which can receive real-time ROS command	Apr 20	In progress
	Hardware integration of Acunav Catheter and dVRK	A prototype of dVRK-Acunav that can be actuated through GUI and ROS	Apr 27	In progress
	(Optional) Teleoperation of the catheter using DaVinci dVRK	Documented python file that use PSM and MTM to achieve teleoperation	May 8	Incomplete
	(Optional) Finding a fit surgical application to our DaVinci-assisted continuum robot navigation	A paper of surgical application example that has potential to use dVRK-Acunav	May 10	Incomplete

Project Status-Updated Timeline

Project Mentor:
Dr. Mohammad Salehizadeh, Anton Deguet, Dr. Russel Taylor



Current Approach-Workflow

Minimum(Mar.15) [Done] | Expected(Apr.04) [Done] | Maximum (MAY.10)

Rigid: Cadiere forceps

Studying & Training

- ROS environment
- Joint limit testing
- Simulation: GUI
- Actuation: GUI

Continuum: Endoscope

Experiments for Joint Mapping & D-H Parameters

- Measurements
- Kinematics Model

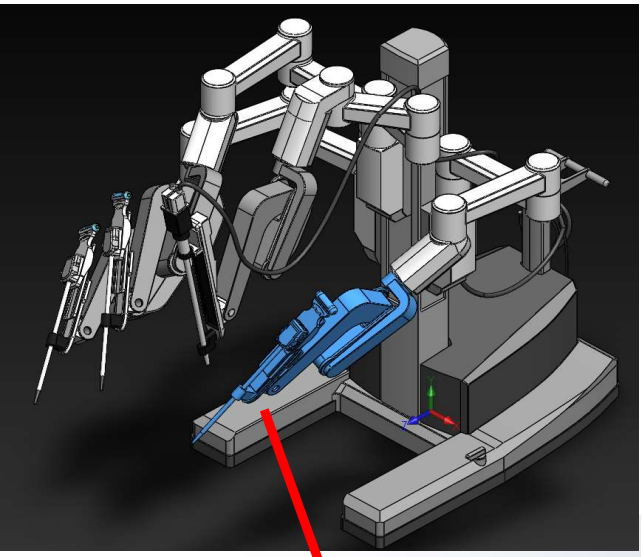
Code development

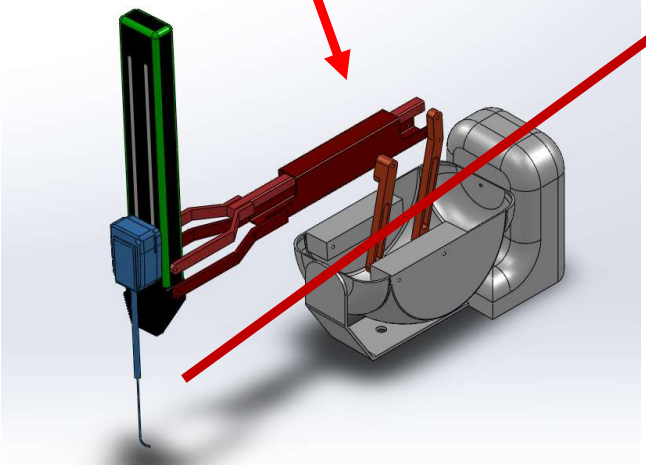
- PSM3
- Forward Kinematics
- Inverse Kinematics

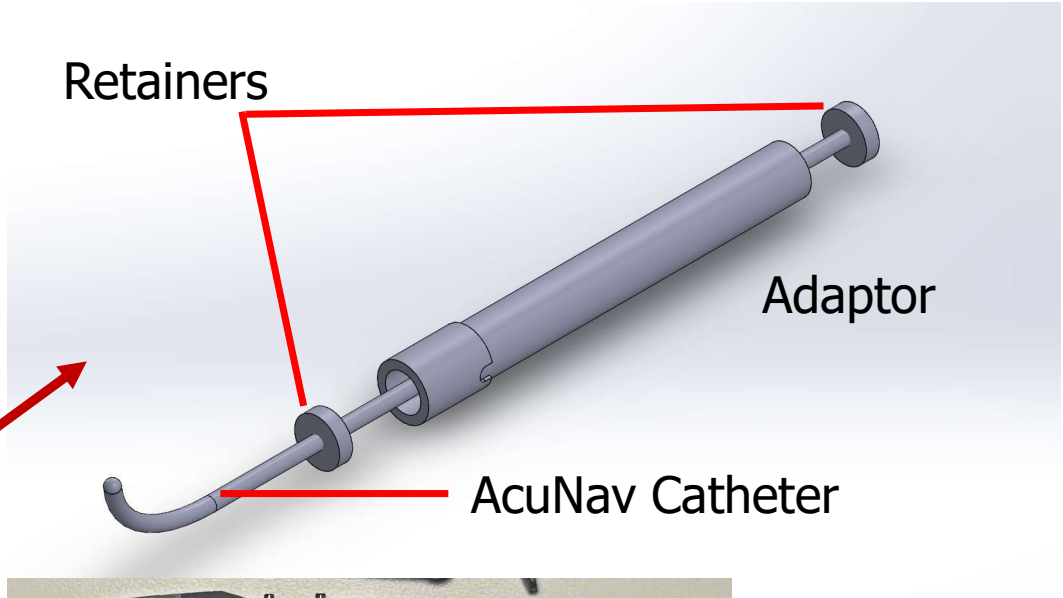
Continuum: AcuNav

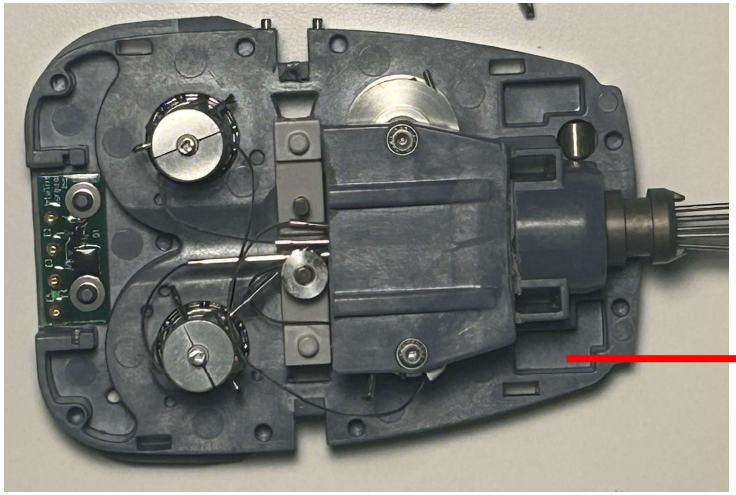
- EM Tracking system
- Prototyping & testing
- Find a fit surgical application
- Teleoperation (optional)
- Ultrasound catheter tracking and imaging (optional)

Current Approach-Adaptor Design



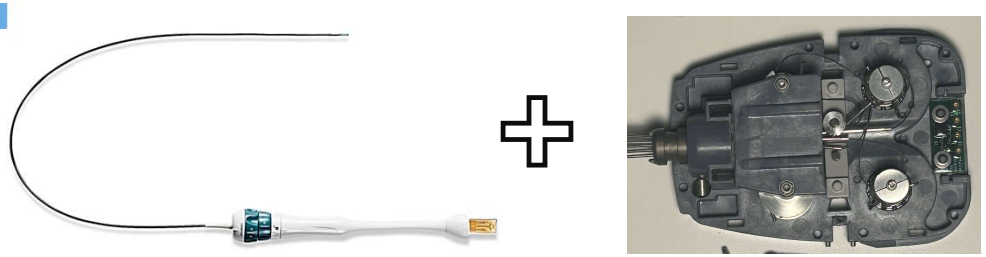


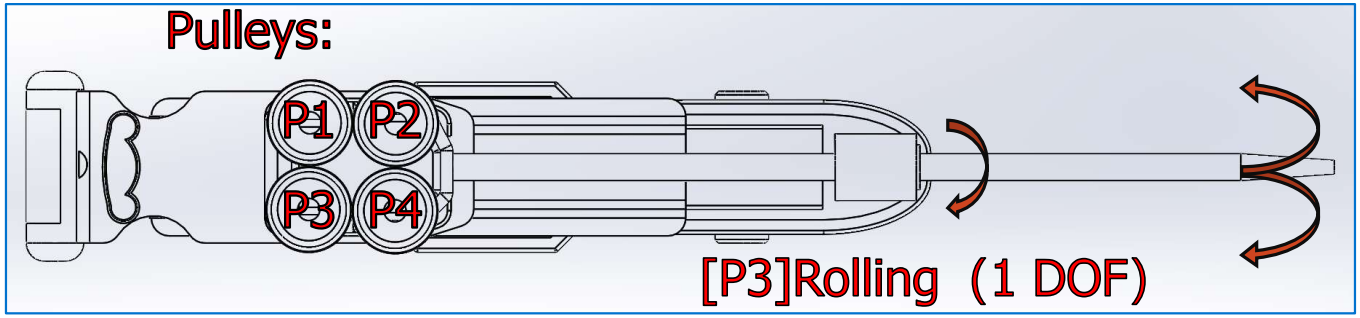




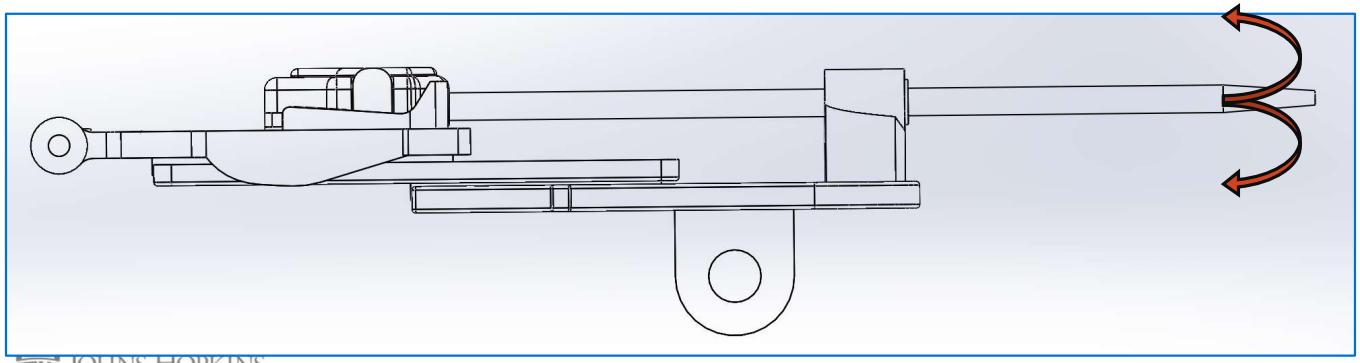
Figures From: https://github.com/jhu-dvrk/dvrk-ros/tree/master/dvrk_model/cad/PSM_CAD_Model

Mechanism of AcuNav-dVRK assembly





[P1]Pitch (1 DOF)



[P2]Yaw (1 DOF)

Total: 3 DOF

Joint Mapping & D-H Parameters

Joint Mapping Functions:

Pitch: $\phi_1 = 2R_c\alpha\cos\theta/D_{knob}$

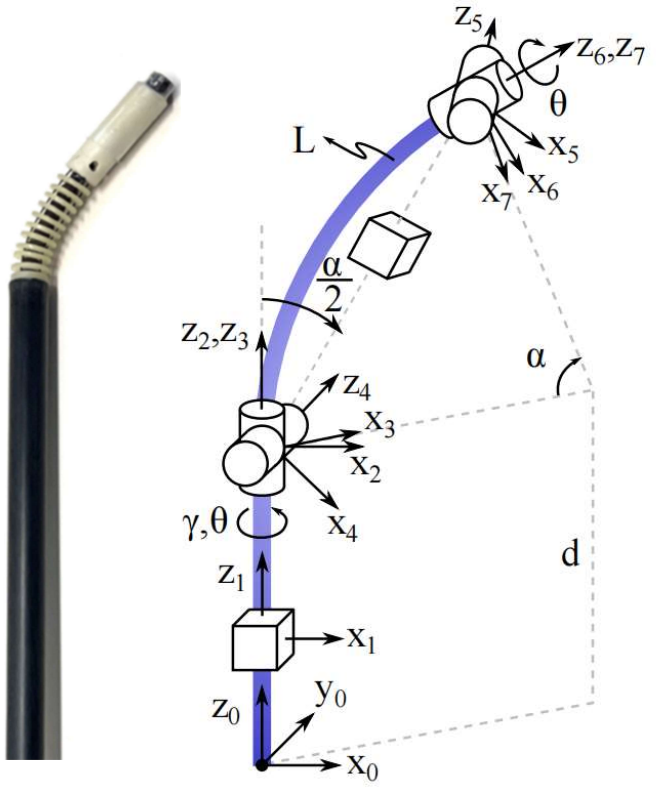
Yaw: $\phi_2 = -R_c\alpha\sin\theta/D_{knob}$

Rolling: $\phi_3 = \gamma$

Translation: $\phi_4 = d$

R_c: Radius of the catheter
D_{knob}: Diameter of Pulleys
d: Translation
α: Bending angle on the plane
γ: Bending plane angle
Θ: Rolling around Z-axis
L: length of the catheter tip

D-H Parameters:

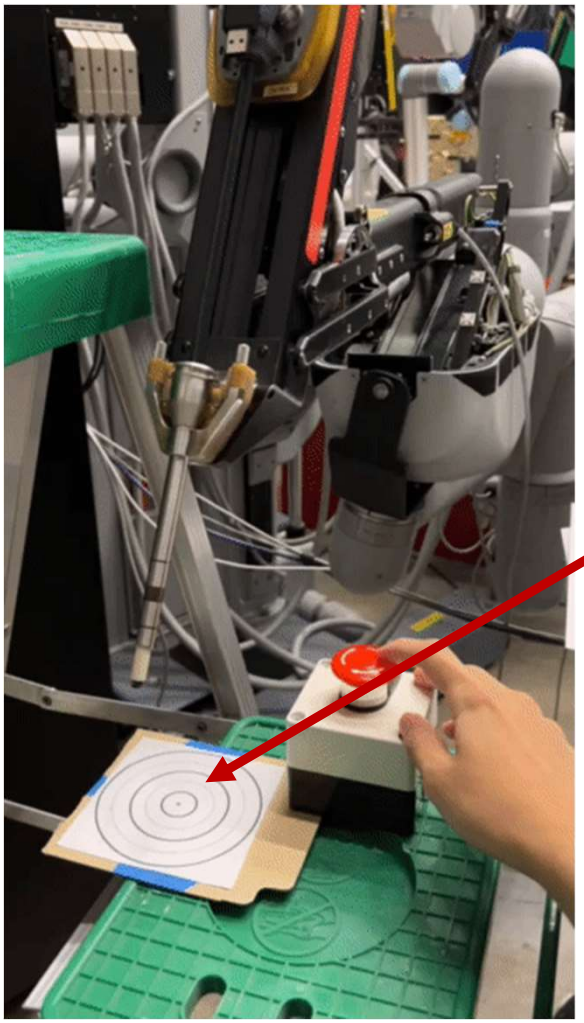


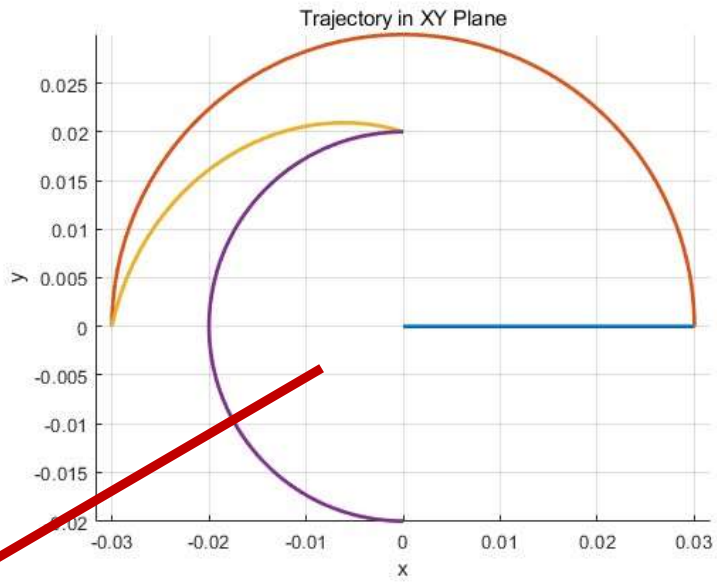
D-H PARAMETERS

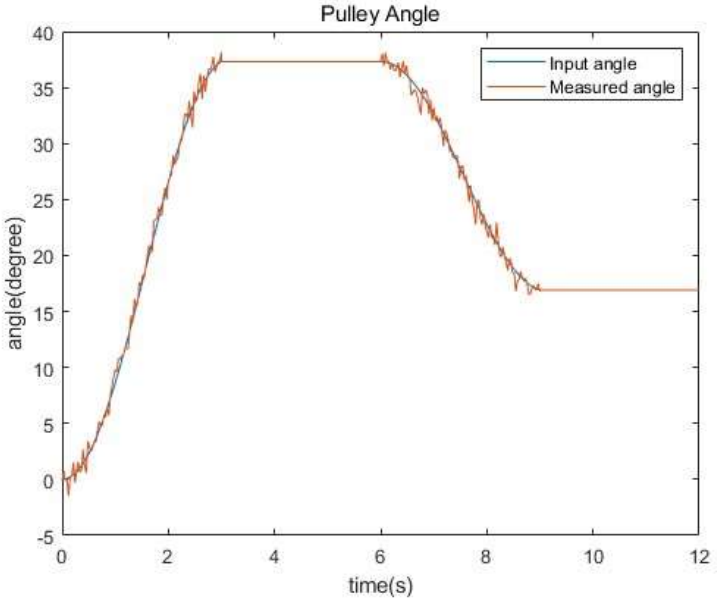
Link	a_i	α_i	d_i	θ_i
$0 \to 1$	0	0	d	0
$1 \to 2$	0	0	0	γ
$2 \to 3$	0	0	0	θ
$3 \to 3'$	0	$-\pi/2$	0	0
$3' \to 4$	0	$\pi/2$	0	$\alpha/2$
$4 \to 5$	0	$-\pi/2$	$2\frac{L}{\alpha}\sin\frac{\alpha}{2}$	0
$5 \to 6$	0	$\pi/2$	0	$\alpha/2$
$6 \to 7$	0	0	0	$-\theta$

Figures and equations From: Degirmenci, A., Loschak, P. M., Tschabrunn, C. M., Anter, E., & Howe, R. D. (2016, May). Compensation for unconstrained catheter shaft motion in cardiac catheters. In 2016 IEEE International Conference on Robotics and Automation (ICRA) (pp. 4436-4442). IEEE.

Demo Video







Rotation

$$\begin{bmatrix} s_{\gamma+\theta}s_\theta + c_{\gamma+\theta}c_\theta c_\alpha & -s_{\gamma+\theta}c_\theta + c_{\gamma+\theta}s_\theta c_\alpha & c_{\gamma+\theta}s_\alpha & Lc_{\gamma+\theta}(1-c_\alpha)/\alpha \\ -c_{\gamma+\theta}s_\theta + s_{\gamma+\theta}c_\theta c_\alpha & c_{\gamma+\theta}c_\theta + s_{\gamma+\theta}s_\theta c_\alpha & s_{\gamma+\theta}s_\alpha & Ls_{\gamma+\theta}(1-c_\alpha)/\alpha \\ -c_\theta s_\alpha & -s_\theta s_\alpha & c_\alpha & d + Ls_\alpha/\alpha \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Position

Transformation Matrix

Future Work

- Replace endoscope with AcuNav catheter
  - Apply existing forward kinematics matrix
  - Implement control algorithms
- Utilize EM tracker
  - Measure tip displacement
  - Reduce error to acceptable range
- Explore potential applications
  - Precise control of the catheter
  - Teleoperation capabilities

dVRK-endoscope

Acunav catheter

NDI EM-tracking system

Responsibility Distribution

- Chenhan Zhang
  - Master's Student, ME Major, responsible for Mechanical Design and Tool model
- Jaspor Jiang
  - Master's Student, Robotics Major, responsible for Verification Test and Documentation.
- Heyun Wang
  - Master's Student, ME Major, responsible for Forward Kinematics Build and Control algorithms .

Management

- Weekly meetings
  - Student team meeting: brainstorming, three times a week
  - Lab meeting: dVRK training
  - Mentor meeting: progress report, 3:30 PM-5:30 PM each Friday
- Platforms:
  - Zoom, Email: communication
  - Github: codes
  - Microsoft Teams: communication, documentation

Reading list

1. Jessica Burgner-Kahrs, D. Caleb Rucker, and Howie Choset. 2015. Continuum Robots for Medical Applications: A Survey. Trans. Rob. 31, 6 (Dec. 2015), 1261–1280. https://doi.org/10.1109/TRO.2015.2489500
2. T. Kato, I. Okumura, S. -E. Song, A. J. Golby and N. Hata, "Tendon-Driven Continuum Robot for Endoscopic Surgery: Preclinical Development and Validation of a Tension Propagation Model," in IEEE/ASME Transactions on Mechatronics, vol. 20, no. 5, pp. 2252-2263, Oct. 2015, doi: 10.1109/TMECH.2014.2372635.
3. P. Kazanzides, Z. Chen, A. Deguet, G. S. Fischer, R. H. Taylor and S. P. DiMaio, "An open-source research kit for the da Vinci® Surgical System," 2014 IEEE International Conference on Robotics and Automation (ICRA), Hong Kong, China, 2014, pp. 6434-6439, doi: 10.1109/ICRA.2014.6907809.
4. Kesner SB, Howe RD. Position Control of Motion Compensation Cardiac Catheters. IEEE Trans Robot. 2011 Jul 21;PP(99):1-11. doi: 10.1109/TRO.2011.2160467. PMID: 21874124; PMCID: PMC3160644.
5. An Open-Source Research Kit for the da Vinci Surgical System, Kazanzides P, Chen Z, Deguet A, Fischer GS, Taylor RH, DiMaio SP, ICRA 2014, May 2014.
6. Cha H-J, Yi B-J, Won JY. An assembly-type master–slave catheter and guidewire driving system for vascular intervention. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine. 2017;231(1):69-79. doi:10.1177/0954411916679328

Reference

[1] Tobe, Frank. “Intuitive Surgical Da Vinci Surgical System Gets Big Endorsement and New Competition.” Robohub, https://robohub.org/intuitive-surgical-da-vinci-surgical-system-gets-big-endorsement/.

[2] “Acuson AcuNav™ Ultrasound Catheter.” Biosense Webster, https://www.jnjmedtech.com/en-US/product/acunav-ultrasound-catheter.

[3] “Ion by Intuitive | Robotic Bronchoscopy Platform for Nodule Biopsy.” YouTube, YouTube, 4 May 2019, https://www.youtube.com/watch?v=0ZaobUiJhCQ&feature=youtu.be.

[4] JHU-dVRK. DaVinci Research Kit. GitHub, https://github.com/jhu-dvrk/sawIntuitiveResearchKit/wiki.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